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Abstract: De Impressionibus Elementorum is a treatise written by Robert Grosseteste, English scientist and philosopher, shortly after 1220 AD. In this treatise we can find a discussion of some phenomena involving the four classical elements (air, water, fire and earth), in the framework of an Aristotelian physics of the atmosphere. For its referring to experiments, this treatise strongly differentiates from similar previous works. Moreover, it contains some descriptions of phase transitions which are rather interesting, in particular when Grosseteste is discussing of bubbles.

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1. Introduction

Robert Grosseteste (c.1175 – 1253) was an English scientist and philosopher, bishop of Lincoln from 1235 AD until his death. As told in [1], he was commentator and translator of Aristotle, and in fact, in the scientific works that Grosseteste wrote, we may find several references to the Aristotelian physics. In the "De Iride", "On the Rainbow" [2] for instance, Grosseteste is explicitly citing one of the Aristotelian works, that on Meteorology. This treatise contains Aristotle's theories about the earth sciences, including the water evaporation, some weather phenomena, and earthquakes. Let us remember that the Aristotelian physics was based on the four classic elements (Air, Water, Fire and Earth), to which the Philosopher added the Aether. This is the quintessence, the fifth and highest element in ancient philosophy that permeates all nature and is the substance composing the celestial bodies. Aristotle is then describing in the Meteorology a spherical lithosphere (Earth), a hydrosphere (Water) and the atmosphere (Air and Fire), surrounding them. He considered that the vapor which is formed during the day rises in the atmosphere to form the clouds, however not too high, because the heat that is raising it "cannot lift it to a great height but soon lets it fall again" [3]. Not surprisingly, Aristotle is considered the father of climatology and geophysics [4,5].

After this short remark on the Aristotelian ideas on earth and atmosphere, we can read one of the scientific treatises written by Grosseteste, entitled "De Impressionibus Elementorum". This title is usually translated as "On the Impressions of the Elements". Let us note that "impressio" in Latin means "assault, impetus, vehemence," and, figuratively, "perception"; then another translation of this title could be "On the Impetus of the Elements", a title good to enhance the presence of physics in the Grosseteste's approach. According to R.C. Dales, in this treatise, written shortly after 1220, the main features of Grosseteste's scientific method are clearly in evidence, so that it strongly differentiates from similar works of the twelfth century [6]. Let us note that in this and in several other treatises written by Grosseteste, there is a constant referring to experiments.

At the beginning of the XIII century, some of the medieval scholars were strongly influenced by the Aristotle's philosophy, which had begun to circulate in France in Arabic translation, introduced from Spain [7,8]. With this Aristotelian revival, we have a reassessment of using the four classical elements in discussing physics, to feature the simplest principles which are ruling the world. Most frequently, these classical elements refer to the phases of matter and then the Earth is a solid, Water a liquid, Air a gas, and Fire is the heat. Even in the poetry and religious songs of the XIII century we find the four elements to describe the Creation, such as in the Canticle of the Sun, composed by Francis of Assisi [9].

As we will see reading De Impressionibus Elementorum, Grosseteste is discussing how an element can be changed, for instance the ice in water and the water in vapor, by using heat and fire. Quite interesting is the discussion on bubbles. Here in the following I am giving a translation of the Latin text in Ref.10. A translation of this work was also given by R.C. Dales [6]. The aim of my translation is that of enhancing physics.

2. On the Impetus of the Elements

As told by James in his letter (James.1.17) "every best thing and every perfect gift is coming down from the Father of Lights, with whom there is no mutation or shadow of change". However, let us consider that, under some circumstances, this is immediately resulting, but in other cases it needs mediation. Therefore, the philosophers, even if they are not perfectly able of understanding the facts, ought not to

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be ignorant of the nature of things: and so, they do not ignore that the rays of the heavenly bodies falling upon the physical things provide the greatest cause of their changes, such as the rays that, when reflected and condensed, are the cause of heat generated among us. A proof of this is the fact that the heat is greater in the valleys than on the mountains; and then snow remains longer on the mountains than in the valleys; and on some high mountains snow remains perpetually.

And let us note that it makes no difference, that the sun is hot in itself. For if the body of the sun were considered as hot in itself and its heat exciting heat in the things below it, then the closer a thing were to it the warmer it would be, and on the tops of the mountains there would be greater heat than in the valleys and in the upper and medium layers of air more heat than in the lower layer; but we see all the opposite facts, because the snow remains on the tops of the mountains, not in the valleys; and in the upper layer of air the hail is generated and in the lower the rain. A sign of the same: the birds of prey in the summer fly high to cool themselves, like the eagles flying very high, to mitigate the heat generated from their movement; they fly so much. The cranes and many other birds come down in the valley to escape ice and frost, on the other hand, to escape hot climate they go up to the mountains. And all these are signs of the same, that is, that heat is not transferred directly from the solar body, but from the reflection and condensation of rays.

Under these conditions it is clear that the rays go down deep in the water, being the water a transparent medium such as air, icicle and glass. Therefore, some deviation of rays exists in deep waters, then, the heat is greater at the bottom than at the surface. Hence, at the bottom of waters, the fishes live during the winter, but, in summer, they can live near the surface; during the winter, the water is frozen at the surface, however, not in its depths.

If anyone asks the following, that is, why the water congeals when it is very cold, being coldness its natural power, as it seems to be humidity and fluidity, we answer to this person that all the water is naturally cold, but not fluid; by its nature, it is frozen indeed. The fluidity results from the heat absorbed, for softening the bulk.

Again, the rays reflected from a concave mirror generate fire and tinder is ignited. Therefore, having established that the heat is clearly coming from a condensation of rays, we have that, being them condensed in the bulk of water, the water is heated, and even heated so much that it does not keep its nature of water: it passes, therefore, to the nature of the air. But, to the nature of the air, it is not proper being under the water: it comes out, over the water, and rises in a bubble as in an ampoule made of the same water. However, when several bubbles ascend on the water, due to the nature of their wet films, barely can they remain themselves, and from them, vapor or steam is formed, by which the clouds are made. But, when the generation of bubbles is in the depths of the waters, some of these bubbles pass through the earth, some remain in the waters, and some rise above the water.

Let us first talk about what is rising. If anyone wants to see this directly, put some clear water in a clear vessel, and you will perceive clearly the bubbles generated and rising, created by the heat of the fire being placed under the vessel. Let us remark that we have the same mode of generation of bubbles as discussed here and as previously told.
We have to note yet that with air and bubble there are earth and fire. In the bubble, therefore, there are the four elements, that is, the earth because of the place of generation, the air which is generated, the nature of fire during the generation of heat, and of course some water. Then, here we find a sort of first generation of the elements and the first mixture of them. When there is an abundance of water in the generated bubbles, that is, when they rise from water, we call it "humid vapor"; when earth is abundant, we call it "dry smoke"; when air is predominant, we call it "dense vapor". Then, the rising vapor rises according to the quantity, coarseness and subtlety of the generation of heat. If the heat is great and coarse, the generated bubble is great and coarse and heavy. Sometimes, it is rising just to the surface of water and there breaks imperceptible and the heat evaporates. And when the heat is more subtle, the bubble is more subtle and then weaker the heat that evaporates.

Then, bubbles do not separate from the earth surface and float here and there in the valleys. However, this occurs in the evening and in the morning, when the heat is weak, and so mist is formed. And when these small bubbles dissipate their heat, fall on the earth surface and create dew. However, if the heat is greater, it makes these aforementioned bubbles to rise at the first layer of the atmosphere. There are a first, a second and a third layer in the atmosphere. The third, however, is not at a height greater than fifty miles, as the Philosopher (Aristotle) says. The clouds are in the first atmospheric layer: sometimes each bubble loses its heat, and, being in the cloud, moves itself in the depth of the cloud. And then, the bubbles separate from each other and fall as small droplets. Drops occur indeed, although the cloud is continuous, and because it had not entirely deprived of heat, the rain falls, fluid and not frozen. By the way, let us note that the generations of rain and dew differ according to size and according to the different places of generation.

However, when the cloud rises to the second layer, there is a further loss of heat, and then the bubbles are left utterly deprived of their heat at a subsequent stage, and for this reason we have that they remain soft as wool, and become snow. However, if the cloud is suddenly rising to the second layer, suddenly is the heat lost and round stones, as the bubbles round, appear and hail is generated. This occurs especially when it is hot. However, hoar-frost is different from the ice coming from clouds, such as rain differs from dew.

3. Discussion

When Grosseteste was bishop of Lincoln, he used to end the treatises writing "Explicit tractatus secundum Lincolniensem". Here, there is not this sentence: it means that the treatise was written before 1235, in fact shortly after 1220 [6].

At the beginning of the treatise, Grosseteste is addressing the problem of heat transfer. We know that there are three methods by which heat is transferred: conduction, convection, and radiation. Conduction and convection are supported by solid and fluid media. But they cannot account for some of other phenomena, for instance, the heat we feel when sitting in front of a fire or under the sun. And then is seems that Grosseteste knew this aspect of the heat transfer, in particular by radiation, as distinguished by conduction. Let us also observe that Grosseteste noted a temperature gradient in the water of lakes and linked the temperature of water to the life in the lakes. However, the behavior of the thermal gradient in a lake is rather different [11].

The element Water, Grosseteste explains, is cold and wet. This is in agreement with Aristotle: in his "On Generation and Corruption", Water is primarily cold and secondarily wet, that is, the water is defined more by cold than by wet [12]. Therefore, Grosseteste continues, the Water, which is naturally cold, becomes fluid because of heat. For the other elements: Air is primarily wet and secondarily hot, Fire is primarily hot and secondarily dry and Earth is primarily dry and secondarily cold. That is, we have four elements and four features (wet, dry, hot, cold) that can be used to describe the natural phenomena, and, among them, the phase transitions. In reading the treatise then, we find that Grosseteste is talking about the phase transition from solid to liquid, the melting of ice, and that is happens because heat is absorbed. The phase transition occurs due to a change in energy of the participating particles. If the water is in the solid phase and the kinetic energy of molecules is sufficiently increased, we change the solid to liquid. In the solid phase, the molecules prefer to assume the lowest energy assembly: after the transition in the liquid phase, the total energy is larger. Let us say that Grosseteste was arguing that "cold" means a lower energy state of a substance.

For what concerns the bubbles, let us consider the following interesting fact: in his Latin text, Grosseteste is not using the word "bulla" for bubble, but he prefers "ampulla", ampoule, which is a small glass vial. It means that he observed that these bubbles were objects, which were spherically contained volumes of vapors, made from a liquid. Rising at the surface of water, the wet films forming the bubbles break and the vapor inside them creates a cloud of steam, as we can easily see, as Grosseteste is suggesting, by observing the boiling water in a vessel.

It is suitable to remember that evaporation and boiling are different, and surely Grosseteste noted the difference, because he tried to distinguish the great and coarse bubbles from the very subtle ones. The boiling of a liquid happens at the boiling point of it, that is, at the temperature at which its vapor pressure equals the environmental pressure. At the boiling point, the vapor pressure overcomes the atmospheric pressure and it is allowed the bubbles to grow in the bulk of the liquid and rise. However, liquids may change to a vapor at temperatures below their boiling points through the process of evaporation. Evaporation is a surface phenomenon in which molecules escape outside the liquid as vapor, without bubbles; boiling is a bulk process in which molecules escape, resulting in the formation of vapor bubbles within the liquid.

Besides boiling, bubbles are present in the so-called effervescence process, which is the process creating the sparkling wines. It is the result of the interplay between CO_2-dissolved gas molecules, tiny air pockets trapped within microscopic particles during the pouring process, and liquid properties (Ref.13 summarizes the physicochemical processes behind the nucleation, rise, and burst of bubbles found in glasses poured with sparkling wines). However, even tap water produces some bubbles too. The water has air dissolved in it. The amount of air that can be dissolved increases with pressure but decreases with temperature. Water in the tubes is usually colder than room temperature, and then the solubility of air in it is higher: as the water is poured, it warms up and the solubility of air is reduced. The air comes out even creating some bubbles. In fact, the air solute molecules can cluster together to form nuclei. When these nuclei are trapped by some defects on the glass surfaces, they start growing forming bubbles in the solution. Experimenting with tap water, we see a slow formation and growth of bubbles, but if carbonated water is used, due to the excess of CO_2-dissolved gas, the bubbles form and grow rapidly. Supposing that Grosseteste observed

the evaporation of water and the contemporary formation of the bubbles from the air dissolved in it, or even the bubbles in wine, he could have argued that evaporation was accompanied by the formation of very subtle "bubbles".

After his observations on bubbles, Grosseteste describes the mist or fog forming from the surface of water bodies, and connects it with evaporation. The fog is due to the vapor that condenses into tiny liquid droplets in the air. Observing these small droplets in the fog, Grosseteste imagined their origin from vapor through its "bubbles". When vapor rises in the atmosphere, we have a cloud, a visible mass of liquid droplets or frozen crystals.

As previously told, Grosseteste is following the Aristotle's model of the atmosphere, a model that persisted for centuries essentially unchanged [14]. Besides the effort of explaining the meteorological phenomena, it is interesting the Grosseteste's description of the phases of matter, solid, liquid and vapor, and the transition between phases because of the heat involved in the process. Moreover, it is remarkable that he considered the solid state of water as its fundamental state, being necessary some heat to gain its fluidity.

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[9] Francis of Assisi was born in 1182. Son of a wealthy merchant in Assisi, he lived as a wealthy young man. After a pilgrimage in Rome, he started to live in poverty as a friar, and founded the Franciscan order, authorized in 1210 by Pope Innocent III. He is considered the author of the "Cantico delle Creature", in English known as the Canticle of the Sun. This is a religious song, considered to be among the first works written in the Italian language. In it, besides Brother Sun and Sister Moon, the Canticle thanks God for Brother Wind, Sister Water, Brother Fire and Mother Earth, that is he thanks God for the Creation. Francis of Assisi composed most of the canticle in late 1224 while recovering from an illness, the end of it on his deathbed on 1226.
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